Coastal Engineering Technical Note

PHYSICAL MODELING GUIDELINES FOR COASTAL HARBORS

PURPOSE:

To provide information and guidelines relative to physical coastal hydraulic modeling that can be used by engineers to enhance and optimize all aspects of the design of their coastal projects.

BACKGROUND:

Three-dimensional harbor wave action model studies have been conducted at the U.S. Army Engineer Waterways Experiment Station (WES) since the 1940's. These coastal hydraulic models have played a very large and important role as a design tool and source of insight for solving coastal engineering problems in the United States.

A recent review of small-boat harbor model investigations indicate that coastal model studies have been conducted at 55 sites in the United States and its territories since the early 1940's (Bottin 1992a). Of the 55 harbor sites modeled, 25 projects have been constructed in the prototype. Site specific performance of these completed projects also have been evaluated to determine if they were constructed as recommended, and if they have functioned successfully in the prototype as predicted by the model studies (Bottin 1992a). These reviews and study efforts have resulted in a summary of lessons learned relative to small-boat harbor design (Bottin 1991, 1992a, 1992b; CETN-III-49). Results of the above mentioned studies indicate that physical coastal model studies are excellent tools for studying and optimizing the design of coastal projects.

This technical note discusses small-boat harbor physical models and their uses, in general, as well as design information required to conduct a physical model investigation. Small-boat harbor design and construction personnel can use this information to gain insight into how a physical model investigation may be used to enhance and optimize project designs.

SMALL-SCALE HARBOR MODELS

The hydraulic scale model is commonly used as a design tool to aid in planning harbor development, and in design and layout of breakwaters, jetties, groins, absorbers, etc. to obtain optimum harbor protection and verify and/or define suitable project performance. Modeling techniques and procedures, as well as methods of laboratory data collection, have been maintained at the leading edge of technology, and reproduction in the model of very complicated hydrodynamic phenomena has become possible through experience gained during the conduct of reimbursable work and applied research. The small-scale physical hydraulic model is the most reliable means of determining an optimum plan for harbor or inlet improvements, particularly when short-period wave effects are prevalent. The model can reproduce breaking waves, wave-current interactions, and the simultaneous effects of wave refraction, diffraction, shoaling, overtopping, transmission, and reflection.

Small-boat harbor design is very difficult due to complex hydrodynamics and geometry of most harbors. Physical hydraulic models generally can be used to:

a. Determine the optimum location, alignment, height, length, and type of breakwaters required to provide adequate wave protection in harbor mooring areas and entrance channels and to quantify wave and current characteristics.

b. Determine the location, alignment, and composition of spending beaches and/or other energy dissipating structures inside the harbor area. These may be rubble wave absorbers or concrete absorber units.

c. Determine the optimum length and/or alignment of breakwater or jetty structures required to minimize shoaling in harbor entrance channels. Information on the effects of structures on littoral processes can be gained through the use of model tracer materials.

d. Determine the optimum length and/or alignment of breakwaters, jetties, or spurs required to alleviate undesirable wave-induced cross-currents and/or shoaling in harbor entrance channels. Plans to provide for increased wave-induced harbor circulation and/or flushing also may be optimized through studies and quantification of current velocities developed by various design alternatives.

e. Determine the response of various harbor configurations or expansions to long period wave energy. Nodal and antinodal areas may be identified in the harbor for various frequencies and the water velocities and water surface motions can be quantified at these locations.

f. Determine river flood and/or ice flow conditions that may enter in or adjacent to a harbor and quantify the impact that a structural modification at the harbor will have on these conditions. In addition, qualitative information on bed load riverine sediment movement may be defined.

g. Study and quantify the effects of harbor modifications on thermal stratification through the use of heated and dyed water input at designated locations.

h. Determine tidal currents or seiche generated currents in a harbor or its entrance. Tidal currents through an inlet entrance may be studied and quantified to determine the optimum placement of structures required to stabilize the inlet and minimize maintenance dredging. The model also can be used to study the interaction of waves and currents and how one affects the other. These data can be used to determine navigation conditions at entrances.

i. Determine project impacts on adjacent harbor areas. Model tests can be used to mitigate negative project impacts (i.e., adverse wave and current conditions, sedimentation, surfing, etc.).

During the conduct of model investigations, remedial plans are developed, as needed, to alleviate undesirable conditions that may exist. Design modifications also are tested, if feasible, in an effort to reduce construction costs and still provide highly functional harbor designs.

DESIGN INFORMATION REQUIRED FOR MODEL INVESTIGATIONS

It is very important to determine realistic and accurate design conditions when developing a coastal hydraulic model investigation. The project engineer should be sure that deep water wave characteristics (period, height, direction, spectral shape, recurrence intervals, etc.) have been well defined (measured or hindcast) offshore of the site. Measured prototype wave data and/or hindcast data should be obtained at the site to determine wave characteristics and recurrence intervals, or return periods, needed for the investigation. On the open coast, a wave refraction analysis should be conducted. When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important are the changes in wave height and direction. Wave refraction and shoaling coefficients are determined from deep water to the depth of water simulated at the wave generator in the model. The bathymetry from the wave generator to the harbor site will correctly refract and shoal the waves as they propagate over the model.

To ensure proper wave transformation to the harbor site it is important that recent, accurate bathymetric data are provided. The more detailed the data, the more accurate the model can be constructed. Shoreline details, irregularities, and overbank elevations also are important so that correct overtopping, runup, and reflective characteristics are simulated.

If existing breakwaters, revetments, groins, absorbers, or other structures are present, detailed, as built, data is needed on structure cross-sections, lengths, and alignments. Depending on the required model scale, adjustments are made to sizing of model construction material (stone) to ensure that correct wave transmission, overtopping, and reflection characteristics are reproduced in the model.

Still water levels (swl's) also are important design conditions. They are selected so that wave-induced phenomena dependent on water depths are accurately reproduced in the model. Normally, more wave energy reaches a harbor site during periods when higher water stages occur in the prototype. These may be during the higher water phase of the local tidal cycle or higher lake levels due to seasonal fluctuations. Also, most storms moving onshore are characteristically accompanied by a higher water level due to wind tide and shoreward mass transport. Conversely, however, lower water levels may result in further offshore movement of longshore sediment (i.e. around the head of a jetty into an entrance channel) since the breaker zone is further offshore with the lower swl's. Prior to the conduct of a model investigation critical swl's must be defined.

If sediment movement alongshore is a concern at a harbor site, the project engineer should make sure that the direction of predominant sediment movement is determined prior to a model investigation. He/she also should determine if reversals are probable at the site. Model tests can be performed to qualitatively determine sediment movement patterns and likely areas of accretion or shoaling. To determine the tracer material to be used, the median diameter (D_{50}) of the prototype sediment as well as its specific gravity are required. Observations and an understanding of prototype movement patterns are critical to initial validation of the model. Then, tracer material can be used in concert with incident wave climates to give qualitative indications of scour and accretion patterns and directions of predominant sediment transport.

In areas where harbors are constructed in river mouths and a model study is being developed, river discharge information will be required to determine impacts that harbor modifications may have on river flow characteristics. A range of river discharges for various return periods should be tested. In addition, roughness coefficients (Manning's n values) must be determined so that correct river bed roughness and overbank roughness are simulated in the model. From these values, roughness can be applied to the model bed to simulate realistic conditions. Qualitative data on bed load sediment movement patterns in rivers can be determined in the model. The specific gravity and median diameter (D_{50}) of river sediments must be determined prior to conduct of the model study.

In areas, such as inlets, where ebb and flood tidal currents in conjunction with wave energy can move sediment into a navigation opening or cause meandering of a navigation channel, tidal information will be required prior to a model investigation. Normally, prototype data are obtained over at least a 29-day period to be used as input in the model study. Tidal elevations and tidal current velocities are generally secured during this period. Due to the large size of the prototype area for tidal inlets, a hybrid modeling approach may be recommended. This approach entails numerically modeling the inlet initially to determine site hydrodynamics, and then physically modeling a smaller area to determine wave/current/structure interaction. In some physical model investigations, the entire tidal cycle is reproduced, and in others, only maximum flood and ebb tidal currents are simulated. Generally, for models reproducing the full tidal cycle, extensive validation tests are required prior to conducting tests to determine the impacts of various improvement plans.

Once design conditions have been established, the project engineer must ensure that realistic performance requirements are established against which improvement plans are to be judged as functionally acceptable. Performance of some prototype harbors where model studies have been conducted indicates that the models accurately predicted wave conditions, but wave height acceptance criterion selected were excessive. This, in turn, results in many complaints by local harbor users that excessive wave conditions are occurring in the prototype. For this reason, careful consideration is essential in selecting and defining acceptable project performance criterion.

Although small-boat harbors may be classified in various schemes, each and every harbor is different. Each harbor has a different configuration as well as possible potential problems and design conditions. For clarification on any aspect of small-boat harbor modeling, design conditions required, or site specific design problems, WES engineers and scientists should be contacted for assistance and guidance.

ADDITIONAL INFORMATION:

Contact Mr. Robert R. Bottin, Jr., Wave Processes Branch, CERC, at 601-634-3827 or Mr. Dennis G. Markle, Chief, Wave Processes Branch at 601-634-3680.

REFERENCES:

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